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PARTICLE SAMPLING AND ANALYSIS IN DABOB BAY, WASHINGTON.(U)
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13 September 1982

Particle Sampling and Analysis in Dabob Bay, Washington

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Preface

This report was prepared under the "Improved Performance Underwater Vehicle LDV-2 Program," Project C33363; Block Program Manager T. Davis; Principal Investigator M. Cincotta (Code 3634). The sponsoring activity is the Naval Sea Systems Command, Program Manager, F. Romano (Code 63R3).

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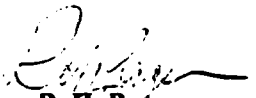

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The concentration of particles in the water column was correlated with turbulence in the boundary layer of experimental underwater vehicle B-1 in Dabob Bay, Washington, in 1979. With the advent of field testing of experimental vehicle LDV-2 in the same location, a more comphrehensive particle sampling program was implemented in 1980.

From samplings taken from August through December 1980, the average total number of particles in the size range 50 - 2000 μm was 14,063/m³.

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During the same time period, fecal pellets in the size range 100 - 1000 µm averaged 7399/m³, or 53 percent of the total particles observed. For all sampling dates, particle sizes of 3.6 to about 50 µm, as determined by a Coulter Counter, were the most abundant, averaging 3181 x 10⁶/m³, or five orders of magnitude greater than the larger particles taken by the net.

For the 74 µm mesh net samples, 72 percent of the particles fell within the size range of 100 - 500 µm. Thirteen percent of the particles were in the size range of 50 - 100 µm. Fourteen percent of the particles were in the size range of 500 - 1000 µm, whereas less than 1 percent were in the range above 1000 µm.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

PARTICLE SAMPLING AND ANALYSIS IN DABOB BAY, WASHINGTON

INTRODUCTION

A brief sampling program in 1979 indicated that the breakdown of laminar flow in the boundary layer of experimental underwater vehicle B-1 was caused by the concentration of particles in the water column. The experimental vehicle was operated and the samples were taken in Dabob Bay by Dynamics Technology, Inc.* Although it was not determined what particle-size range was the most significant, it was apparent that the particles affecting vehicle performance were almost exclusively members of the plant (phyto) and animal (zoo) plankton and that as such they could be collected by conventional biological sampling metholds. With the advent of the LDV-2 (low drag vehicle) field test program in 1980, it was decided to try to determine the particle-size ranges in Dabob Bay routinely with the LDV-2 performance tests. Accordingly, a sampling program was devised by the Naval Underwater Systems Center (NUSC), the Applied Physics Laboratory (APL) of the University of Washington, and Dynamics Technology, Inc. This report describes the particle sampling program, laboratory analyses, and representative results.

METHODS

The LDV-2 test depth was determined for each run by APL and NUSC primarily from echogram records that gave an indication of the larger size plankton distribution throughout the water column. It was also deemed important to run the LDV-2 below 30 m in order to avoid the turbulence associated with the pycnocline, and because particles may concentrate in the resulting sharp density stratification. Bottle and net samples taken from a research vessel were completed by APL within 1 hour of the LDV-2 run. The 105 kHz echograms were taken both before and during the net tows.

BOTTLE SAMPLES

At the beginning and end of each sampling run, two 5-liter water bottle samples were taken, one 5 m above and one 5 m below the predetermined LVD-2 test depth. The samples were then refrigerated, but not preserved. Analysis of the samples by APL included Coulter Counter counts and plant pigment and biomass determinations. (Data from the plant pigment and biomass analyses are included in the appendixes of this report.) Coulter Counter counts of the material were conducted within 6 hours of collection.

In the Coulter Counter, electrical current flows through a small aperture between two electrodes. Particles possess insulating qualities, and, as each passes through the aperture, pulsations in the current are sensed by the electronic counting circuits. (It should be noted that the Coulter Counter is designed to count spherical particles; cells with other shapes are usually not satisfactorily enumerated.[1]) The Coulter Counter used employed a 200 μm orifice, with 15 channels spanning a size range of 2.8 to 90.5 μm.

* Dynamics Technology, Inc., has prepared an unpublished report titled "Correlation of Intermittency Results with Particulate Data."

The counter was calibrated according to the methods of Sheldon and Parsons,[2] which resulted in the determination of particle sizes exceeding 3.2 μm. There is the possibility of noise contamination in particle counts for sizes below 4.48 μm. Counts were made on an 0.5 cc sample and a 10 cc sample. In most cases for the 10 cc samples, significant counts were obtained only for particles less than 50 μm (table 1).* For this report, the 10 cc counts were averaged over the sample depths for each test run. Data were reported by APL as counts/cc.†

NET SAMPLES

To determine particle size and concentration above the range of the Coulter Counter, plankton nets were towed at about 3/4 to 1 knot for approximately the length of the LDV-2 run, at test depth and adjacent to the path of the LDV-2. A distance of 1000 to 2000 yards is considered appropriate to ensure a representative sample of plankton, which is usually quite "patchy" in distribution both vertically and horizontally.

Because of plankton patchiness and the relatively shallow sampling depths, vertical tows were not considered to yield representative samples. Moreover, vertical sampling with open nets integrates over depth and does not provide a sample at a selected depth. However, for comparison with the B-1 particle data, one series of vertical tows was taken on 27 October with the 74 μm net between the depths of 46–36 m and 110–88 m. The samples were analyzed by J. A. Runge, a graduate student at the University of Washington.

Since no one mesh size can satisfactorily collect all particle sizes of interest, two 0.5 m diameter nets of different mesh size were attached side by side on the same frame. The nets had mesh sizes of 74 and 200 μm, respectively. The nets were designed to sink to depth closed, to open for towing, and to close again for retrieval. This method avoids contamination from waters above and below the required sampling depth. A flow meter installed in the mouth of the 200 μm mesh net provided an estimate of the volume of water filtered. The average volume sampled for the eight tows, from 15 August to 18 December, was 265 m^3. Samples were taken at other dates but are not reported since the vehicle runs were aborted or discontinued.

The samples obtained with the nets were preserved with 10 percent formalin/sea water. In the laboratory, the net samples were divided into 1/16 or 1/32 portions with a Folsom splitter. The abundance and the sizes of the particles in the split were determined at APL and NUSC either by direct microscopic examination and/or by separation into size categories by sieving followed by microscopic examination. Fractionation by sieves divided the particles into the following sizes in microns: 100 - 299, 300 - 499, 500 - 999, 1000 - 1999, $\geq$ 2000.

Although the sieve technique used by APL is generally faster and allows for analysis of larger subsamples than does the direct microscopic examination technique, the sieve method has a major disadvantage; namely, many particles are very irregular in shape, which can alter their retention characteristics, so that they are artificially sized. Particles that are long enough but not

* Tables 1 through 5 are located at the end of the main text of this report.
† There are 10^6 cc per m^3.

wide enough to be retained by the smallest sieve size (100 μm), may pass through the screen and be lost to analysis. Phytoplankton and fecal pellets, which are usually quite abundant, were not generally noted or enumerated on the screens. Conversely, under direct microscopic examination, which is relatively slow, particle characteristics can be accurately observed, sized, and enumerated.

To provide the best possible estimate of particle sizes and abundances, NUSC reexamined the samples (without sieving) directly under the microscope. In this method, a 1 milliliter aliquot taken from the 1/16 or 1/32 split was counted and sized in its entirety. In both methods used, (sieve and direct), no serious attempt was made to taxonomically classify the particles other than to assign them to generalized categories. However, if the investigator recognized the taxonomic classification of certain particles, the identification was noted.

RESULTS

The great majority of particles occurring in Dabob Bay fall in the size range 3.6 to 9.0 μm (table 2). Numbers determined by the Coulter Counter were five orders of magnitude greater than the total of the particles counted microscopically (figure 1). The abundance of the small particles remained relatively similar throughout the sampling period. That the particles larger than 50 - 60 μm were inadequately counted by the Coulter Counter seems to be corroborated when samples are compared under direct microscopic examination. Relatively large numbers of particles in the size range 40 - 100 μm were observed and counted under the microscope, but comparative Coulter counts were either absent or minimal (tables 1-3). In addition, since the 74 μm mesh net theoretically collects particles to a minimum size of 74 μm, particles less than 74 μm that were collected and subsequently observed microscopically were certainly underestimated numerically.

The net data presented here are from the 74 μm net only. This net appeared to collect satisfactorily (as did the 200 μm net) with little clogging, as indicated by the data reported by APL. Because the 74 μm net overlapped the size range of the Coulter Counter analysis, comparisons could be made between microscopic examination and the Coulter Counter.

The particles in the net samples were exclusively of biological nature and included small amounts of detritus.* The composition of the particles estimated by the Coulter Counter is not known at this time, but according to the literature, the material is usually of biological composition. In the net samples analyzed, fecal pellets made up a sizeable portion (13-91 percent) of the material collected (tables 3 and 4 and figure 2) and spanned the size range 100 - 1000 μm. Copepods, copepod nauplii, diatoms, armored dinoflagellates, and molluscan larvae made up the bulk of the other materials in the net samples. Of note is the observation that very few of the particles between 50 and 2000 μm were spherical in shape. Representative particle shapes are shown in figure 2. The most abundant animals -- the copepods -- have more or less cylindrical bodies with large extending antennae and six pairs of legs extending downward. Fecal pellets are definitely cylindrical in shape, but tend to be less rigid in structure than the copepods or diatoms.

* Dead organic and inorganic amorphous matter.

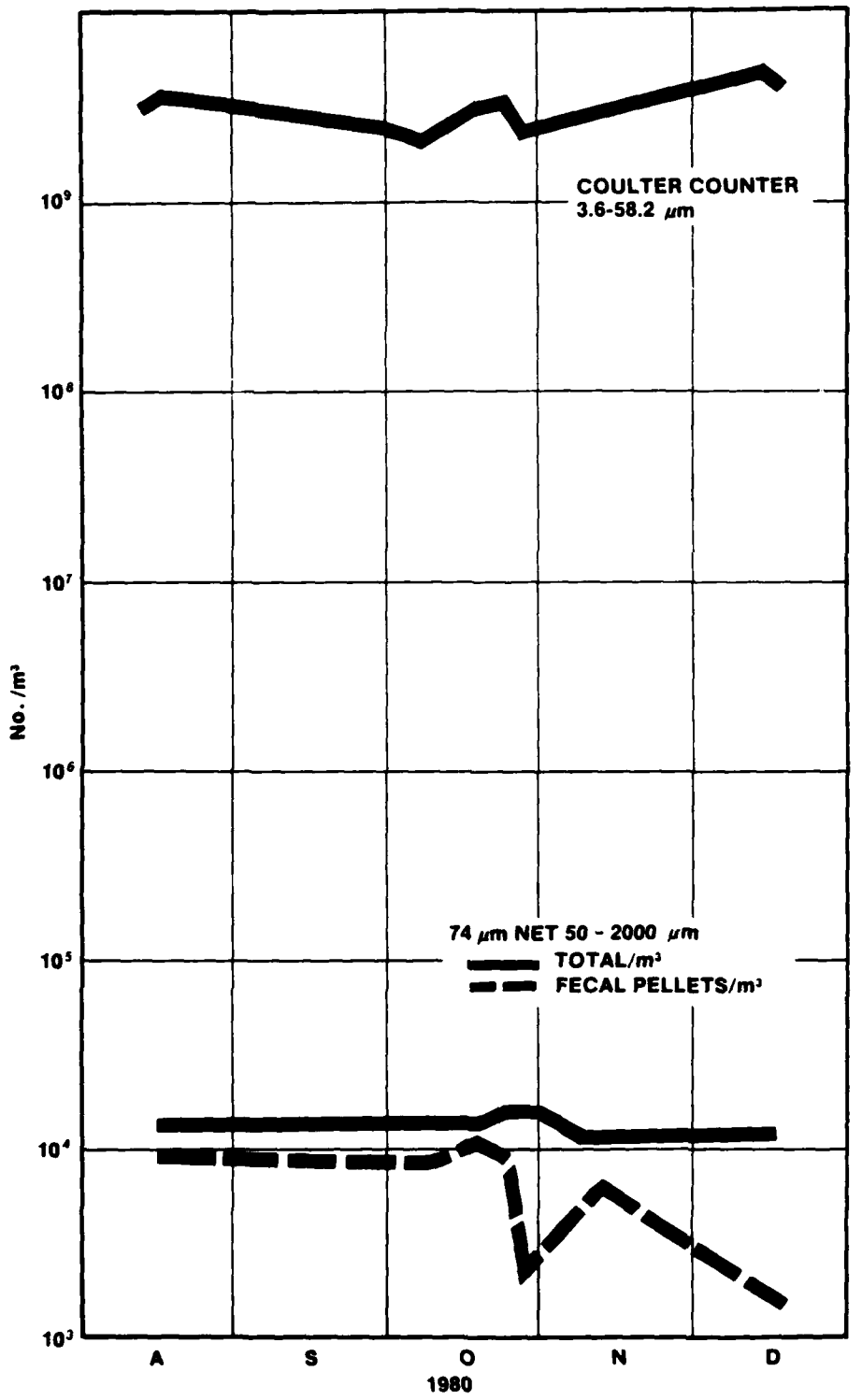

Figure 1. Concentration of Bottle and Net Particles/m³

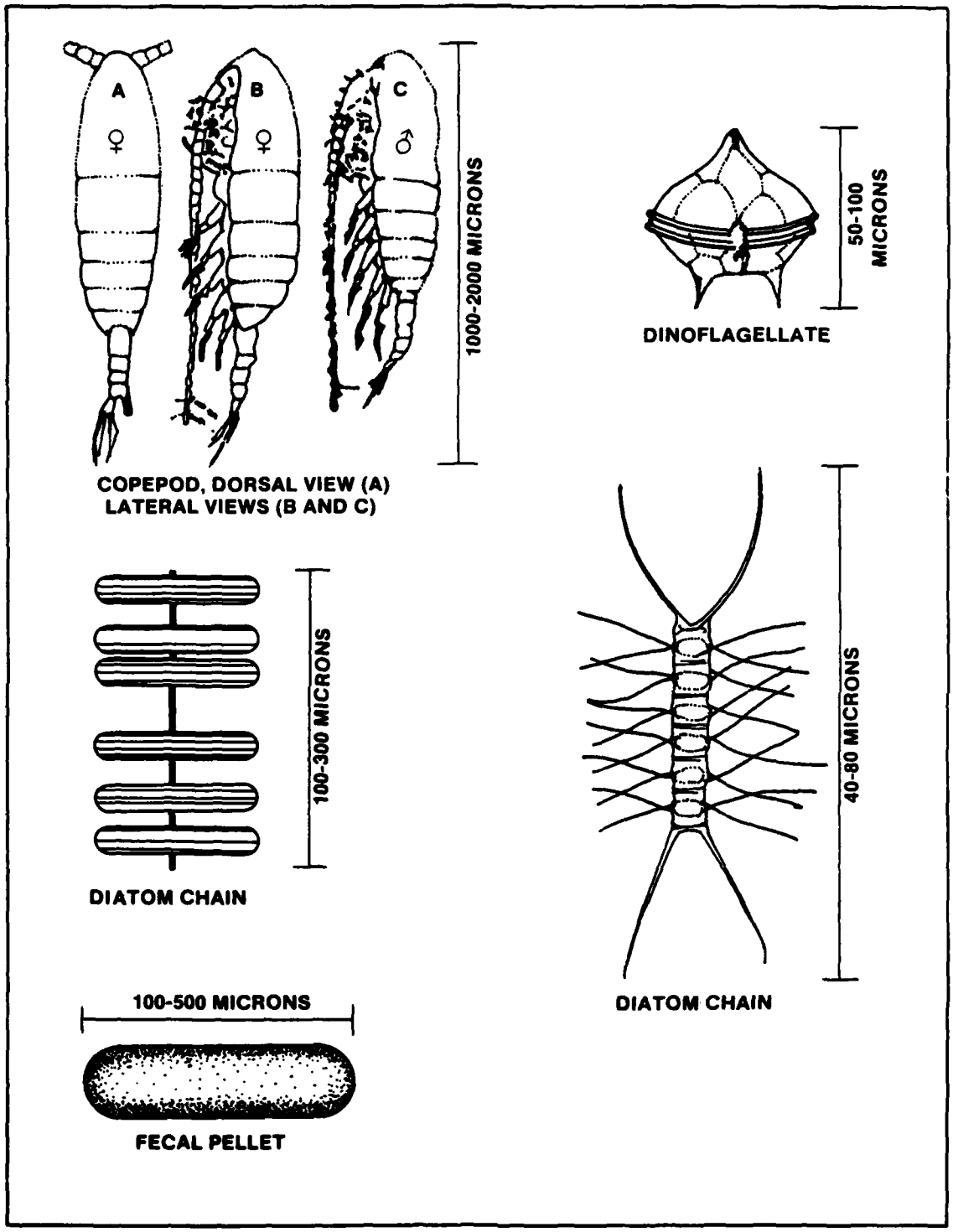

Figure 2. Shapes and Sizes of Representative Plankton

The bulk of the larger phytoplankton in Dabob Bay are composed of single-celled diatoms which are often united to form relatively long chains, with some species having long extended "spines." The armored dinoflagellates are somewhat spherical, but their actual cell wall is composed of heavily sculptured plates.

The composition of the external wall of these four major particles differs greatly. The skeleton of copepods is composed of chitin, a tough and resistant polysaccharide. Fecal pellets (primarily of plant remains) are covered with a thin organic membrane. Diatoms have cell walls of silicon dioxide (glass) whereas the cell walls of armored dinoflagellates are composed of layers of cellulose. These particles are relatively "tough" in the natural environment, but they may break apart fairly easily when brought into contact with more rigid moving structures such as plankton nets or underwater vehicles.

The average densities of the three most common particles found in Dabob Bay are slightly greater than that of sea water (table 5). The density of the sea water varied little over the sampling period, as expected.

Echogram records taken at 105 kHz from 15 August through 18 December revealed no significant signals in the water column at the LDV-2 test run depths. The lack of signal indicated no large concentration of particles in the size range of approximately 4 cm or larger. However, strong signals were observed during all runs at depths of about 55-75 m and below. These records varied both horizontally and vertically and were good indications of relatively large concentrations of plankton and larval or juvenile fish. In the future, a higher frequency (approximately 200 kHz) echo sounder would be helpful to resolve concentrations of particles in the 1 cm size range.

The majority of the particles in the net samples were in the size range 100 - 500 μm. Very few particles were observed above 1000 μm (table 3). As expected, size-frequency distributions varied with time. At a given depth, biological particle distribution may vary with light levels, hydrography, life cycle phase, nutrients, etc.

On 18 December samples were taken at 15 m and 43 m depths. The shallower depth contained more particles than did the deeper depth, but the total count may not be statistically significant because of variations in sampling and analysis procedures. However, the composition of the particles at the two depths was markedly different; fecal pellets were five times more abundant at the shallower depth. Other size-frequency classes differed as well.

In addition, the particles in the 400 - 700 μm size category were copepods and, in this case, were probably the origin of the fecal pellets. Denser concentrations of larger particles are to be expected at relatively shallow depths at night in most bodies of water.

The analysis of the vertical tows taken on 27 October showed that the total concentration (33,243/m^3) of particles at 46-36 m was about twice that (14,829/m^3) at 110-88 m. That the counts at 46-36 m were also about twice that (16,972/m^3) of the horizontal tow taken on the same date at approximately the same time can be explained by the fact that the analyst (J. A. Runge) counted detrital matter in the vertical tows whereas NUSC and APL did not. The composition and size-frequency distribution of the particles from the vertical and horizontal tows were consistent.

Valid comparisons cannot be made between the vertical tows taken for the B-1 program and the present study because, during the B-1 program, a 216 µm mesh net was employed and samples were collected for different months and a different year July and September 1978). The difference in mesh size would account for the greater number of smaller particles captured during the present study than during the B-1 program. The annual and seasonal differences would also influence the variability. During the B-1 program, vertical tows taken on 20 September between 40-20 m yielded approximately 2 x 10^3 particles, whereas between 100-40 m, approximately 1 x 10^3 particles were observed.[3]

SUMMARY AND CONCLUSIONS

From the samplings taken from August through December 1980, the average total number of particles in the size range 50 - 200 µm was 14,063/m^3. Fecal pellets averaged 7399/m^3, or 53 percent of the total particles. Particles sizes of 3.6 - 50 µm, as determined by the Coulter Counter, were always the most abundant, averaging 3181 X $10^6/m^3$, or five orders of magnitude greater than the 74 µm net particles.

From the 74 µm net samples taken from 15 August through 18 December 1980, 72 percent of the particles fell in the size range 100 - 500 µm. Thirteen percent of the particles were observed in the size range 50-100 µm. Fourteen percent of the particles were found in the size range 500 - 1000 µm, whereas less than 1 percent were noted in the size range above 1000 µm.

It is recommended that, in the future, all particle enumeration be conducted by direct microscopic examination without size partitioning using sieves. Thus, use of the microscope has the added advantage of allowing direct observation of particle characteristics and composition.

For particle size classes below 50 µm, instruments other than the Coulter Counter may be more advantageous. Microscopic examination at this level would be extremely slow and tedious, so that an automatic counter is highly desirable. It may be possible to develop other automatic counters to enumerate over a wider size range, say from 3 to 150 µm.

Field instruments have been developed that provide estimates of particle concentrations while being towed through the water.[4] Acoustic devices have also been utilized experimentally to estimate particle concentrations.[5] At the present time, however, sampling with nets and bottles appears to be the most practical technique.

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Table 1. A Representative Coulter Counter
Particle Count, 27 October, Depth 38 m (Numbers X 10^6 = No./m^3)

Mean Channel Dia.(μm)	Counts Per cc 0.5	10
3.59	1046	1175
4.48	436	508
5.74	230	262
7.18	116	144
9.02	60	73
11.47	26	33
14.35	10	18
18.01	8	6
22.8	4	2
28.7	0	1
35.7	0	0
45.3	0	0
58.2	0	0
77.8	0	0
Total	1976	2223

Table 2. Bottle Sample Particle Count Summary,
(Coulter Counter Average No./m^3)*

Date	Depth (m)	Size RANGE (μm)	Nos.X10^6
8/11	100	3.6–45.3	3258
8/15	40	3.6–58.2	3810
9/30	40	3.6–58.2	2676
10/8	40	3.6–58.2	2297
10/10	40	3.6–58.2	2663
10/17	40	3.6–45.3	3163
10/23	40	3.6–35.9	3304
10/27	40	3.6–45.3	2271
11/12	40	3.6–58.2	2907
12/15	40	3.6–58.2	4558
12/18	40	3.6–28.7	4084

* For all dates the majority of particles counted by the Coulter Counter were in the size range 3.6 - 9.0 μm

Table 3. Sizes (μm) and Numbers of Particles From 74 μm Net Samples Counted Microscopically

			15 Aug 1980, 38 m						Fecal Pellets		
Size Range	60–100	100–299	400–720	1200–2400					100–500	1500	
Mean Size			600						200–400		
No./m^3	1440	1043	980	10	10				9078	10	
			10 Oct 1980, 43 m						Fecal Pellets		
Size Range	60	70	100–299	300–499	500–999	1000–1999	≥2000		100–299	300–499	500–999
No./m^3	938	447	1206	938	938	44	1		4969	2946	528
			23 Oct 1980, 43 m						Fecal Pellets		
Size Range	60	80	100–299	300–499	500–999	1000–1999	≥2000		100–299	300–499	500–999
No./m^3	140	295	536	138	186	26	5		7927	4911	919
			23 Oct 1980, 41 m						Fecal Pellets		
Size Range	60	70	100–299	300–499	500–999	1000–1999	≥2000		100–299	300–499	500–999
No./m^3	89	447	2592	983	2011	0	0		5946	3929	7810
			27 Oct 1980, 41 m						Fecal Pellets		
Size Range	60–130	100–299		300–499	500–999	1000–1999	≥2000		100–7000		
Mean Size	80								200–400		
No./m^3	402	7788		4467	2223	249	52		2193		
			12 Nov 1980, 41 m						Fecal Pellets		
Size Range	40–60	60–130	100–299	300–499	500–999	1000–1999	≥2000		100–500		
Mean Size		80							200–400		
No./m^3	255	2412	1031	410	53	3	1		6688		
			18 Dec 1980, 15 m						Fecal Pellets		
Size Range	40–60	100–260	400–700	1000–1999	2000				100–800		
No./m^3	3584	2918	1075	3	1				6758		
			18 Dec 1980, 43 m						Fecal Pellets		
Size Range	40–60	70–80	100–260	400–700	1000–1999	2000			100–500		
No./m^3	2150	2419	2598	3584	7	3			1613		

Table 4. Number or Particles/m^3 From 74 μm Net

Including Fecal Pellets								
Date	8/15	10/10	10/17	10/23	10/27	11/12	12/28	12/18
Depth (m)	38	41	43	41	41	43	15	43
No./m^3	12,751	13,351	15,083	16,778	16,872	10,853	14,339	12,374
Number of Fecal Pellets/m^3								
No./m^3	9,088	8,443	13,757	10,656	2,193	6,688	6,758	1,613
% of Total in Net	71	63	91	63	13	62	47	13

Table 5. Water Density of Dabob Bay and Selected Particle Densities

	Depth (m)	*Water Density (g/cm^3)*
9/18/80	30–40	1.023
10/08/80	30–40	1.023
10/17/80	30–40	1.023
12/15/80	15	1.022
	40	1.023

		Particle Density (g/cm^3)
Calanus finmarchicus (very common zooplankton)	Nauplii	1.045–1.049
	Stage V	1.0255–1.0256
	Adult	1.043–1.047
Fecal Pellets		1.28
Coscinodiscus sp. (very common phytoplankton)		1.19

Appendix A

BIOMASS AND PLANT PIGMENT DATA

The data presented in table A-1 were derived from the sample bottles. At this time there does not appear to be any direct relationship between these data and LDV-2 performance; consequently, no analysis was conducted on these data. However, they are presented here in case the data should become important in the future. In addition, the data in table A-1 may be utilized to draw inferences between net and bottle values and, possibly, to compare with other seasonal or geographical data.

Table A-1. Means and Standard Deviations (s.d.) of Dry Weight of Suspended Particulate Matter, Chlorophyll a, and Phaeopigments, Dabob Bay, Washington, August - December 1980

Date 1980	Location l=launch r=retrieve	Depth (m)	Dry Wt. Particulate (mg/ℓ) mean ± s.d.		Chlorophyll a (µg/ℓ) mean ± s.d.		Phaeopigments (µg/ℓ) mean ± s.d.	
11 Aug.	l	97	0.549	0.249	0.022	0.002	0.176	0.006
		101	0.567	0.202	0.013	0.0	0.196	0.004
	r	97	1.312	0.209	0.038	0.007	0.244	0.028
		101	0.492	0.092	0.022	0.022	0.198	0.009
15 Aug.	l	35	0.786	0.111	0.092	0.006	0.394	0.001
		40	0.704	0.074	0.074	0.004	0.360	0.018
	r	35	0.824	0.149	0.084	0.018	0.395	0.001
		40	0.736	0.111	0.080	0.012	0.388	0.012
30 Sept.	l	38	0.407	0.204	0.048	0.005	0.171	0.047
		43	0.541	0.345	0.040	0.010	0.284	0.056
	r	38	0.500	-----	0.188	0.013	0.300	0.043
		43	0.540	0.168	0.090	0.014	0.299	0.040
8 Oct.	l	38	0.496	0.019	0.036	0.017	0.182	0.034
		43	0.513	0.091	0.039	0.019	0.276	0.263
	r	38	0.513	0.067	0.034	0.005	0.136	0.022
		43	0.566	0.073	0.028	0.005	0.142	0.019
10 Oct.	l	38	0.367	0.155	0.119	0.010	0.347	0.057
		43	0.877	0.323	0.080	0.016	0.359	0.086
	r	38	0.464	0.213	0.058	0.011	0.236	0.016
		43	0.568	0.230	0.045	0.017	0.345	0.090
17 Oct.	l	38	0.521	0.231	0.032	0.004	0.141	0.035
		43	0.377	0.066	0.068	0.022	0.103	0.027
	r	38	0.121	0.037	0.030	0.005	0.127	0.006
		43	0.369	0.100	0.041	0.020	0.110	0.018

Table A-1 Continued

23 Oct.	l	38	0.790	0.255	0.272	0.097	1.575	0.517
		43	0.685	0.159	0.208	0.100	0.991	0.459
	r	38	0.439	0.192	0.247	0.108	1.494	0.368
		43	0.868	0.213	0.338	0.096	2.057	0.579
27 Oct.	l	38	0.433	0.116	0.149	0.090	0.912	0.612
		43	0.297	0.149	0.241	0.070	1.334	0.276
	r	38	0.294	0.099	0.142	0.032	0.718	0.285
		43	0.430	0.076	0.121	0.042	0.406	0.055
12 Nov.	l	38	0.916	0.095	0.035	0.001	0.143	0.013
		43	0.486	0.253	0.040	0.003	0.144	0.011
	r	38	0.939	0.241	0.029	0.004	0.118	0.016
		43	0.300	0.163	0.031	0.006	0.098	0.023

Reverse Blank

Appendix B

PARTICLE CONCENTRATIONS IN DAVID TAYLOR MODEL BASIN (DTMB)

On 9 January 1981, particle sampling and analysis was conducted by APL in the DTMB during LDV-2 testing. Water samples for Coulter Counter analyses were taken with a bucket in stirred-up bottom water and surface water. The same net system used in Dabob Bay was employed.

The Coulter Counter value for a 10 cc subsample of stirred-up bottom water was about equal to that of the average count at a depth of 40 m in Dabob Bay, i.e., about 3000 counts/cc. For the surface water in DTMB, the particle concentration (1674 counts/cc) was about half that of Dabob Bay. No particles larger than 36.0 μm were counted in DTMB; as in Dabob Bay, the majority of the particles were between 3.6 and 7.2 μm.

As expected, the average concentration of particles in the DTMB net samples was appreciably less than that of Dabob Bay. Because the DTMB particles consisted of nonliving material, no serious attempt was made to classify it. The average number of particles from the net samples was less than 1 percent of that collected in Dabob Bay. The breakdown is as follows:

Size (μm)	100–299	300–499	500–999	1000–1999	≥2000
No./m^3	15	4	2	<1	<1

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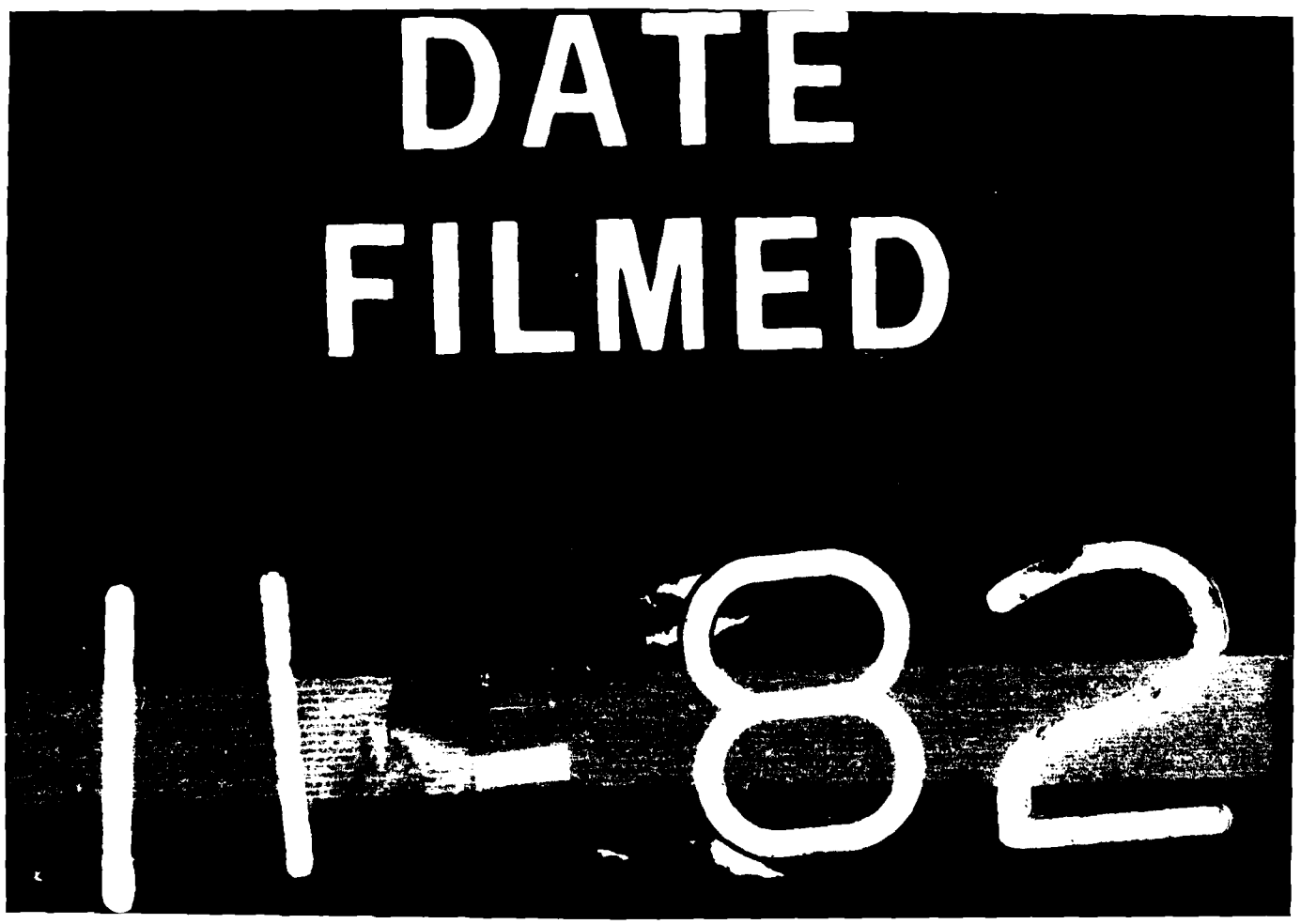
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